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MODELING OF THE STRUCTURE OF HEAT-INSULATING FOAM GLASS

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The structure of high-porosity materials whose structure has a complicated organization, containing macro- and micropores, amorphous and crystalline phases, and other heterogeneous inclusions, is modeled.

Foam glass is one of the most effective heat-insulating building materials, which has a unique set of properties and a wide range of applications. However, despite this, only foam glass made by foreign producers is offered in the market for building materials. In our country, the production of foam glass is in the beginning stages. This is primarily because the technological regimes have not been adequately worked out. Although the production of foam glass is a relatively simple process, there are problems associated with the complicated heat treatment of the specially selected batch.

Analysis of heat treatment of foam glass batch shows that two main stages can be identified according to structure formation. At the beginning of heat treatment, the material possesses a finely dispersed structure, whose particles sinter and then foam up as a result of intense release of gases by the foaming agent. At the final stage of foaming, the pores in the material reach their maximum size, and from this moment the structure of the article no longer changes substantially throughout the entire next stage of production. Foam glass has a high temperature and is in an easily deformable plastic state, which requires a structure to be fixed as rapidly as possible. For this, the article is subjected first to rapid cooling and then the temperature is stabilized over the cross-section of the material. At the final stage of heat treatment of foam glass annealing is necessary to remove residual stresses.

These two stages can be studied separately, independently of one another.

The present article is focused mainly on the production stage for foam glass — with a formed structure. Aside from macropores the foam glass at this stage contains micropores and crystalline inclusions. Thus the system is quite complicated. Empirical data alone and the simplest loading regimes (stretching, compression, shear, and so on) are not sufficient to study the system. Detailed modeling of the interaction of the structural elements is necessary.

There are two main approaches to modeling the structure of porous materials — discrete and homogeneous. In the homogeneous method it is necessary to determine the thermophysical characteristics of a homogenized insulation system (thermal conductivity, specific heat, and so on). In view of the complex organization of the structure, this approach is undesirable and will not produce significant results of practical value. This situation is unacceptable. In addition, in this case the final goal of mathematical modeling is to determine the stresses formed during heat treatment of foam glass, and for a homogenized model it is difficult to take account of the characteristic features of their distribution in the porous body. For foam glass it is necessary to determine the maximum admissible stresses and the elastic modulus, which are required to calculate and monitor the quality of annealing and which depend on a large number of factors (porosity, density, degree of perforation — the presence of open porosity); this requires additional experiments.

In summary, the discrete approach to solving the modeling problems posed is most effective.

In the model which we propose the material is described by a certain number of spherical particles with a small diameter and constant composition, characteristic for a structural element of foam glass. The particles are indivisible. Under an external load they do not deform but rather their arrangement in three-dimensional space changes. The diameter of a particle changes only when the temperature of the particle changes (as result of thermal expansion or compression). The interaction between particles occurs at the point of contact and is determined by the strength of the bonds between the (the ultimate strength under stretching, compression, or sheer).

The arrangement of a particle in space changes as result of a redistribution of the entire collection of particles making up the structure of the material. Deformation occurs with a deviation from an equilibrium mutual arrangement of neighboring particles.

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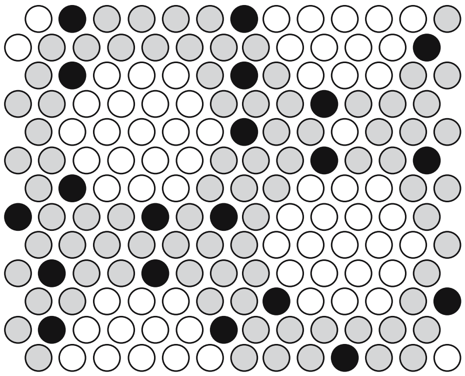

Fig. 1. Diagram of the geometric model of a porous body.

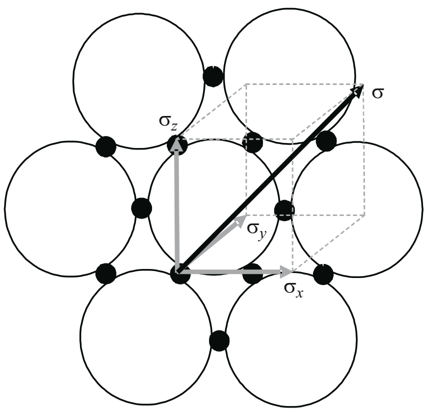

Fig. 2. Formation of stresses σ in the proposed model of a porous body: σ_x, σ_y, and σ_z — stress the vectors.

Pores in a high-porosity material are likewise described by a collection of spherical particles, but particles which possess the properties of a gas.

A simplified diagram of the model of a porous body is displayed in Fig. 1.

A similar approach to modeling heterogeneous materials makes it possible to switch to an analysis of the internal interactions in an elementary volume, considering the entire system to be homogeneous (no gaseous inclusions) and using the simplest forms of loading. Thus, as result of an external action on a porous system only the relative coordinates of the elements of the model change (under an external load) or the diameter changes (with a change in temperature), or both occur (in the presence of a temperature gradient and external load). When the coordinates of the points of interaction between individual elements of the model, obtained as result of an external action, differ from the coordinates in the free (unstressed) state, deformation of the structure will occur and therefore stresses will appear (Fig. 2).

The magnitude of the stresses in this case will be determined by well-known laws for elastic (Hooke's law) and viscoelastic (taking account of relaxation theory) states.

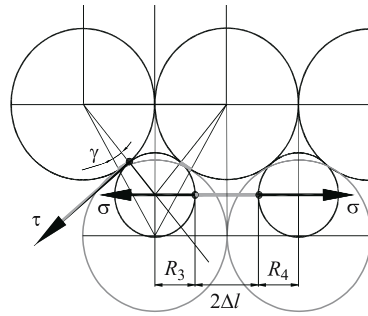

Fig. 3. Model of the stress – strain state.

The model is based on the fact that, initially, foam glass in the equilibrium state consists of spherical particles with the same radius, equal to unity, and all changes in the sizes of the particles occur as result of thermal expansion. In the calculation, the geometric arrangement (coordinates of the points of contact) of all particles in the actual and free states is determined first. The magnitude of the linear deformation is calculated according to the displacement of the coordinates of compatible points of neighboring particles (Fig. 3):

$$\Delta l = \frac{2R_2 - (R_3 + R_4)}{2}, \tag{1}$$

where R_1, R_2, and R_3 are the radii of the elementary particles of the model.

The free size of an element is determined by its CLTE.

For glass (the main material of the matrix in foam glass), during heat treatment, aside from a changing the distance between particles, the relative position of the particle characteristically changes also (the structure of the glass changes). Such behavior of the material has a large effect on the properties of the glass. In this respect the CLTE does not differ from other properties. Consequently, together with the instantaneous values of the coefficient, when calculating the deformation it is also necessary to take account of the effect of the second, "structural," parts of the so-called equilibrium value of the properties.

In this connection, the free size of an element is calculated according to the formula

$$R_k = 1 - (T_0 - T_{fk})\alpha_e - (T_{fk} - T_k)\alpha_m, \tag{2}$$

where T_0, T_{fk}, and T_k are at the initial, structural, and final temperatures, respectively, and α_m and α_e are the instantaneous and structural CLTE.

The actual size of the element is assumed to be equal to the arithmetic-mean value of all free sizes of mutually bound neighboring elements of the sample being studied [1]:

$$l = \sum_{i=1}^{n} \frac{l'_i}{n}. \tag{3}$$

Since glass is a brittle material, fracture of glass is accompanied by elastic deformations (possibly, with a large fraction of plastic deformations).

According to Hooke's law, for other deformations the presence of deformations of layers of a sample, as determined by Eqs. (1) – (3), is accompanied by the formation of different kinds of stresses in them:

$$\sigma = \frac{E\Delta l}{l},$$

where E is the elastic modulus.

On the other hand, as result of deformation of one element of the model (see Fig. 3) tangential stresses arise because of shear deformations of the particles. In accordance with Hooke's law the tangential stresses τ are determined by the formula

$$\tau = \gamma G,$$

where γ and G are the angle and shear modulus, respectively.

The model constructed in this manner makes it possible not only to determine the magnitude of the stresses arising under deformations of different kinds taking account of the diversity of structural elements but also to investigate the form and character of the stress – strain state of high-porosity composite materials.

REFERENCES

1. O. V. Mazurin, *Vitrification and Stabilization of Inorganic Glasses* [in Russian], Nauka, Leningrad (1978).